

THE ROLE OF BENTHIC MICROALGAE IN THE ECOLOGY OF LAKE ILLAWARRA

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ABSTRACT

Benthic microalgae (BMA) are an important component of shallow coastal ecosystems, as they contribute significantly to primary production, nutrient cycling and sediment stabilisation. Despite the importance of these processes to the health of estuaries and especially coastal lagoons, there are few studies of BMA in Australian estuaries. This study examined the spatial and seasonal variation in the biomass and distribution of BMA in Lake Illawarra, on the south coast of NSW. Sediment cores were collected throughout the lake on 6 occasions between October 1999 and August 2001. The upper 5mm of these sediment samples were analysed for chlorophyll *a*. Water quality and light attenuation were also measured. Biomass of BMA varied from 4.2 – 74.3 mg/m² and was generally higher in shallow sandy areas compared to the deep mud basin. High turbidity is likely to restrict benthic productivity primarily to the shallow areas where light can penetrate to the benthos. However, due to low light adaptation by BMA, increases in water clarity are likely to increase BMA activity and function significantly throughout the lake. This study has highlighted the profound differences in the biological activity of shallow sandy areas vs deep muddy areas within the lake.

INTRODUCTION

Benthic microalgae (BMA) are an important, yet often overlooked, component of coastal ecosystems. As their name suggests, BMA (also known as

microphytobenthos (MPB)) are microscopic algae that inhabit the surface of sediments, and are usually only visible as a greenish or brownish tint (MacIntyre *et al.* 1996). BMA have been recorded from a range of estuarine and marine environments from intertidal and subtidal areas (Beardall and Light 1994). They are composed predominantly of diatoms, but also other taxa such as dinoflagellates and cyanobacteria (MacIntyre *et al.* 1996). The role of benthic microalgae in the ecology of estuaries and shallow coastal waters has recently been highlighted in the literature (Pinckney and Zingmark 1993; MacIntyre *et al.* 1996; Light and Beardall 1998).

Benthic microalgae are important primary producers, contributing up to 30% of the total productivity of an estuary, and often equalling the contribution of pelagic phytoplankton in shallow environments (MacIntyre *et al.* 1996). In well-mixed or turbulent environments, resuspension of BMA attached to sediment particles also contributes significantly to pelagic productivity (de Jonge and van Beusekom 1995; MacIntyre *et al.* 1996). Hence, BMA are a major sink for carbon fixation and form the basis of food webs in coastal environments. In contrast to other benthic primary producers such as seagrasses, BMA are an excellent source of labile carbon for benthic grazers and suspension feeders such as macroinvertebrates and fish (Miller *et al.* 1996). The presence of BMA may also reduce sediment resuspension through the formation of mats on the surface, and binding of sediment particles with extracellular exudates (MacIntyre *et al.* 1996).

A number of factors have been cited as affecting BMA productivity including light, nutrient status, and temperature (Grant 1986; Kromkamp *et al.* 1995; Blanchard *et al.* 1997). Light is the most important factor due to its rapid attenuation through the water column that results in a limited amount of light reaching the benthos. Increased attenuation due to turbidity from suspended sediments or phytoplankton blooms, and filamentous algal growth will further reduce light penetration to the benthos. However, benthic microalgae are adapted to low light levels typically found in turbid, shallow water environments, and adapt quickly to local conditions of light availability (Sundback and Jonsson 1988; Light and Beardall 2001).

Located at the sediment surface, BMA are uniquely placed to play an important role in the remineralisation of organic matter and in nutrient cycling between the sediment and water column. Fluxes of nutrients between the sediment and the water column are regulated through uptake by growing BMA populations. In addition, oxygenation of surface sediment microlayers, as a result of photosynthetic activity, enhances bacterial mediated nutrient cycling, including the process of coupled nitrification/denitrification (Rizzo 1990; Kromkamp *et al.* 1995; Rysgaard *et al.* 1995; Kristensen *et al.* 1997; Pind *et al.* 1997; Fredricks *et al.* 1999). These processes are important in regulating the amount and type of nutrients available in the water column for phytoplankton and algal growth.

Due to the role of BMA in primary production and nutrient processing in shallow coastal waters, information on the biomass, distribution, productivity and photosynthetic characteristics of BMA is required to improve our understanding of these ecosystems and their response to increasing loads of nutrients. Studies in Australian estuaries have shown that

biomass and productivity of BMA are similar to other parts of the world (Lukatelich and McComb 1986; Light 1997; Gay 2002). However, there are few studies of BMA in coastal lagoons in Australia (Fredricks *et al.* 1999). NSW has over 70 coastal lagoons and many of these experience signs of eutrophication (HRC 2003), such as filamentous and harmful algal blooms, anoxia and decreased water clarity. Lake Illawarra has experienced many of these symptoms and is considered to have a mesotrophic status (HRC 2003). Studies by Webster *et al.* (2002) indicate that BMA are likely to contribute significantly to the primary productivity and nutrient dynamics of Lake Illawarra. Therefore, information on the biomass and distribution of BMA is an essential first step in understanding their role in the ecology and nutrient cycling in Lake Illawarra. This information can then be used in to inform predictions of the consequences of altered nutrient inputs into Lake Illawarra.

The aims of this study were to determine a) the differences in BMA biomass between 2 main habitats in Lake Illawarra – deep mud basin and shallow sandy margins and b) the spatial and seasonal variability in the distribution of BMA throughout the lake over a 1 year period.

METHODS

Biomass

Sampling Design

The biomass of benthic microalgae was determined from unvegetated sediments in Lake Illawarra between October 1999 and August 2001 at two spatial scales. Firstly, samples were collected every 3 months to determine spatial variation at scales of 1 – 100's meters at two sites that represent the majority of habitat types in Lake Illawarra, shallow subtidal flats <1m deep on the eastern shores, and the deep mud basin

>2.5m deep (Figure 1). At each site, 4 replicate samples were collected from each of 3 plots (2x2m) that were spaced 10-50m apart. Sites were located approximately 1km apart.

Secondly, the distribution of BMA throughout the lake was determined by sampling an additional 26 sites in October 2000, January and August 2001. At each site, 3 replicate samples were collected for BMA analysis and one large core for grain size analysis. The location of sites was chosen based on a stratified grid pattern to incorporate areas of different sediment, depth and river/ocean influence (Figure 1).

Field sampling

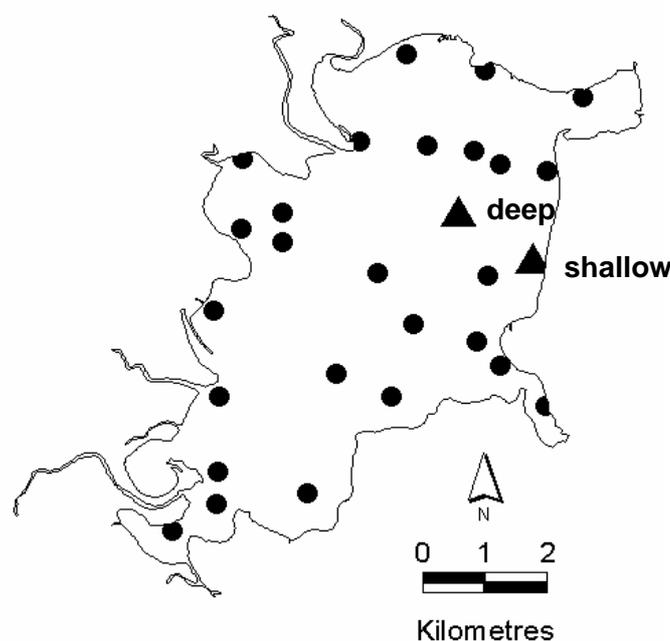
Sediments were sampled using cores of either 22mm diameter (small) or 74 mm diameter (large). In shallow areas (less than 1m deep), small cores were collected by wading through the sampling site,

taking care not to disturb the sediment. In deeper areas, large sediment cores were collected using a remote corer from a boat. Care was taken to ensure the sediment surface was undisturbed. The large cores were then subsampled using the 22mm diameter cores. The top 5mm of the small sediment core was placed in a 30 mL sample tube, wrapped in foil to exclude light and frozen at -20°C . Samples were analysed within 30 days for chlorophyll *a*, *b*, *c* and phaeophytin by spectrophotometry. An additional sample was also collected from each sampling site to determine water content of the sediment sample.

Chlorophyll analysis

Sediment pigments chlorophyll *a*, *b*, *c* and pheophytin were determined using standard spectrophotometric methods

Figure 1: Locations of sampling sites in Lake Illawarra for benthic microalgal biomass. ▲ = spatially replicated sites sampled October 1999 – August 2001, ● = sampling sites to determine lakewide distribution October 2000 – August 2001.



(APHA 1998). Samples for pigment analysis were extracted in 90% acetone in the dark at 4°C for 3.5 hours. A final concentration of 90% acetone was achieved by adjusting the amount of 100% acetone added to the samples according to the water content of the additional sediment sample collected from that site. Extraction was assisted by placing 3 preweighed marbles in each tube and placing extraction tubes on a rotator to grind the samples. After extraction, the samples were then centrifuged for 20 mins and a sample of the supernatant transferred to the spectrophotometer cell. Readings were taken at wavelengths of 750, 664, 647 and 630nm. Two drops of 0.1N HCL were added and readings again taken at wavelengths of 750 and 665nm. The vial containing the remaining sediment was dried overnight at 100°C and weighed to determine the dry weight of sediment. Values for chlorophyll *a*, *b*, *c* and pheophytin were calculated according to Standard Methods (APHA 1998).

Water quality and light

On each sampling occasion, water quality including temperature (°C), salinity (ppt), dissolved oxygen (mg/L), and pH was collected using a water quality meter (Horiba U20 or Hydrolab minisonde). Light (as Photosynthetically Active Radiation - PAR) ($\mu\text{mol}/\text{m}^2/\text{s}$) were collected using a LiCor Underwater Quantum Sensor (LI-192SA). Light attenuation through the water column was calculated using the equation:

$$K = \ln(I_0/I_z)/Z$$

Where *K* is the attenuation coefficient, *I*₀ is the amount of incident light at the surface of the water, *I*_z is the amount of

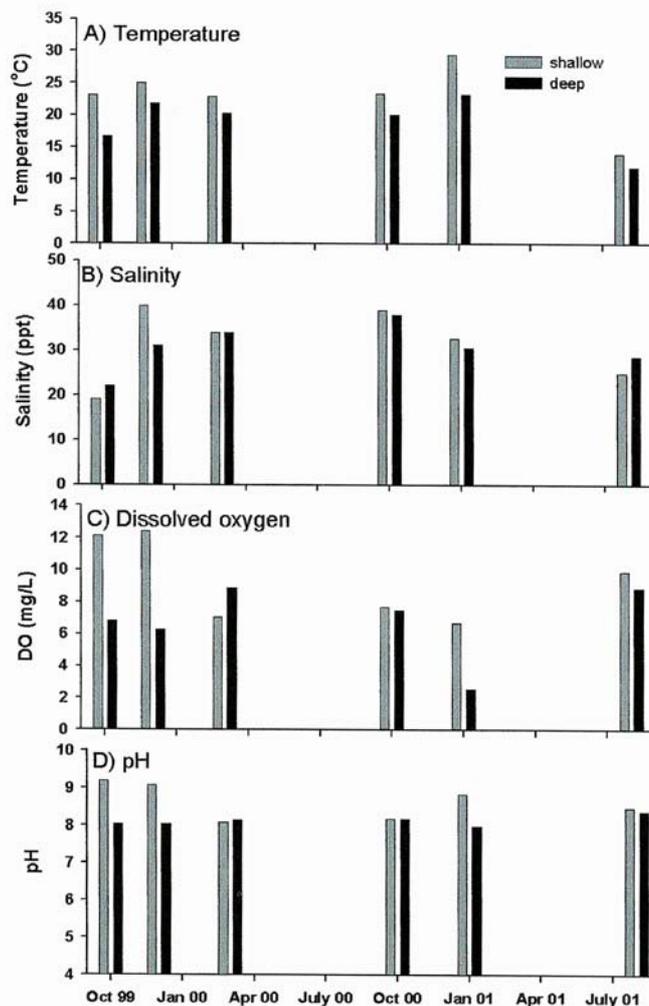
light at depth *z*, and *Z* is the distance between the two measurements.

RESULTS

Water quality and light

Water temperatures ranged between 14.0 – 29.5°C at the shallow site and 12.0 – 23.2°C at the deep site (Fig 2A). On all sampling occasions, temperature in the shallow areas was higher than in at the deep site by 2 – 7 °C. Salinity varied between 20 – 39 ppt over the sampling period depending on entrance condition and rainfall (Fig 2B). Dissolved oxygen ranged between 7.0-12.4 mg/L in shallow areas and 2.6 – 8.9 mg/L in deep areas and was often higher in the shallow areas (Fig 2C). Values of pH were between 8 and 9.2 at both sites (Fig 2D). The proportion and maximum amount of light reaching the benthos at shallow and deep sites is shown in Figure 3. As expected, the proportion of light reaching the benthos at the shallow site is much greater than at the deeper site. The maximum expected PAR reaching the benthos is based on the measured attenuation coefficient and the maximum light recorded on clear day within a month of the sampling time. The maximum PAR at the shallow site ranges from 756 – 1280 $\mu\text{mol}/\text{m}^2/\text{s}$ and 4-140 $\mu\text{mol}/\text{m}^2/\text{s}$ at the deep site. Figure 3: A) Proportion (%) of incident light reaching the benthos at shallow and deep sites in Lake Illawarra calculated from measures of light attenuation at these sites on sampling occasions; B) Maximum amount of light reaching the benthos calculated from A and maximum values of incident irradiance (midday on clear sunny days) at each sampling time. *I*_k = theoretical photosynthetic saturating irradiance.

Figure 2: Surface water quality values (temperature, salinity, dissolved oxygen, pH) recorded at the time of BMA sampling at shallow and deep sites in Lake Illawarra.



Biomass

BMA biomass was generally greater in the shallow sandy site ($4.2 - 74.3 \text{ mg/m}^2$) than in the deep mud basin ($5.6 - 22.0 \text{ mg/m}^2$), except in December 1999 when there were extensive filamentous algal blooms at the shallow site (Fig 4). At the shallow site, biomass was highest during summer (January 2001) and lowest during the winter sample (August 2001). At the deep site, biomass was highest during spring (October 200) and lowest in summer (January 2001).

The distribution of BMA throughout Lake Illawarra changed substantially among sampling times (Figure 5). The biomass of

BMA was greater and more widely distributed in October 2000 compared to January and August 2001. The biomass of BMA is concentrated in shallow areas particularly near the lake entrance and along the eastern shore and southern bays. In January 2001, the biomass of BMA was low throughout the lake with values $>20 \text{ mg/m}^2$ restricted to areas near the entrance.

There was no significant relationship between depth and BMA biomass (Fig 6A) or between grain size and BMA biomass (Fig 6B). However, there was a general trend of higher biomass in shallower sites where sediments were predominantly sandy.

Figure 3: **A)** Proportion (%) of incident light reaching the benthos at shallow and deep sites in Lake Illawarra calculated from measures of light attenuation at these sites on sampling occasions; **B)** Maximum amount of light reaching the benthos calculated from A and maximum values of incident irradiance (midday on clear sunny days) at each sampling time. I_k = theoretical photosynthetic saturating irradiance.

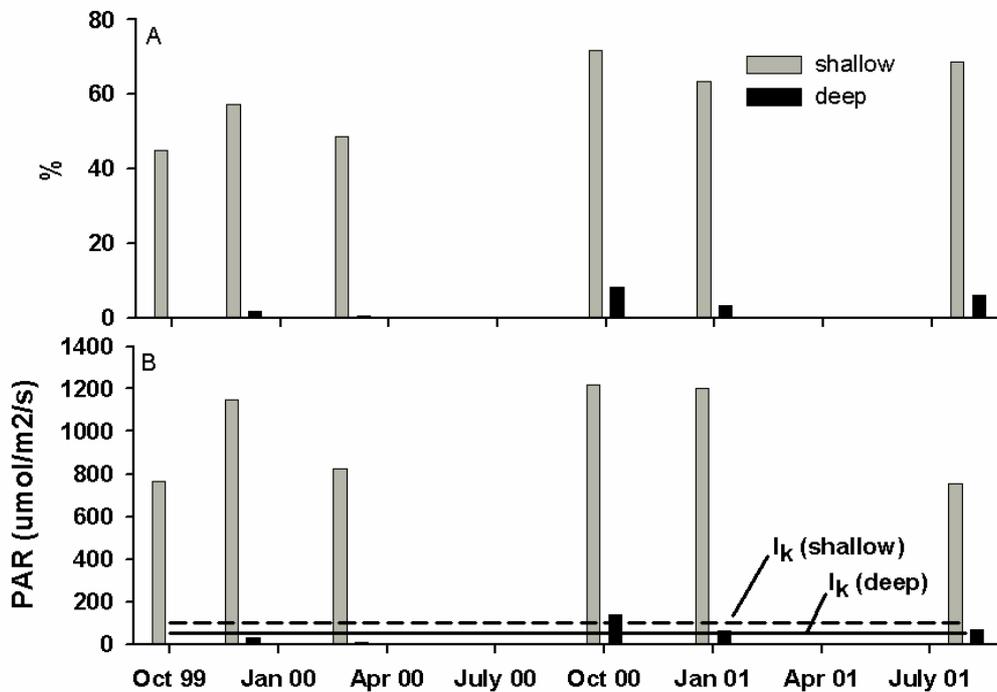


Figure 4: Biomass of benthic microalgae at two sites in Lake Illawarra October 1999 – August 2001.

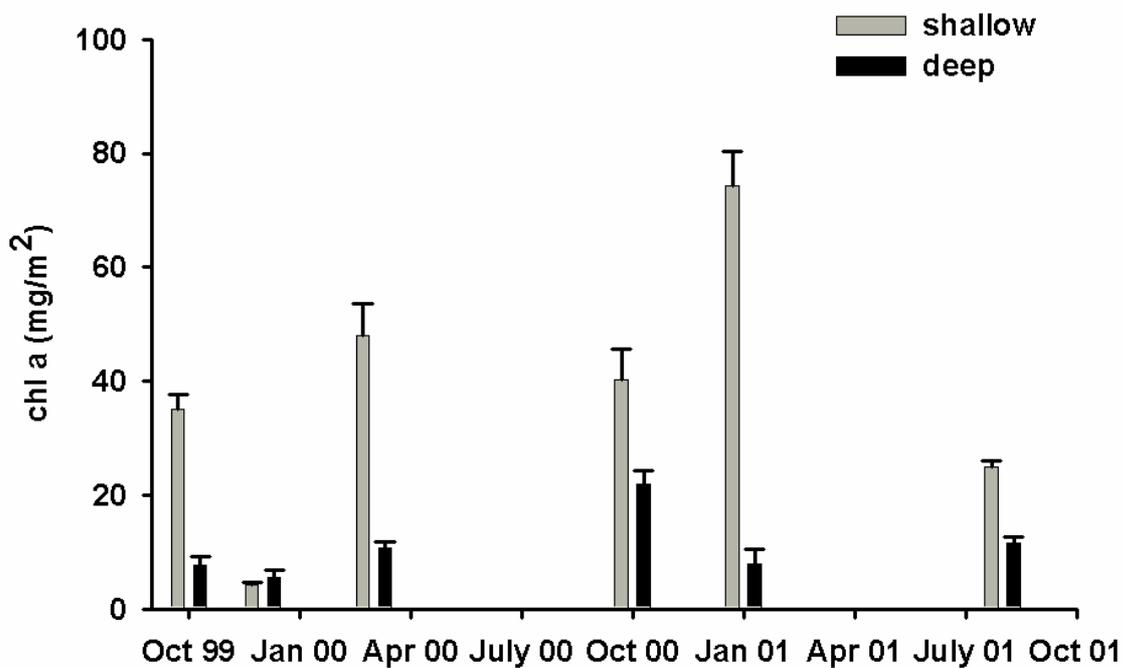


Figure 5: Distribution of benthic microalgal biomass in Lake Illawarra from October 2000 – August 2001. Distribution has been extrapolated from data at each point using ARCVIEW.

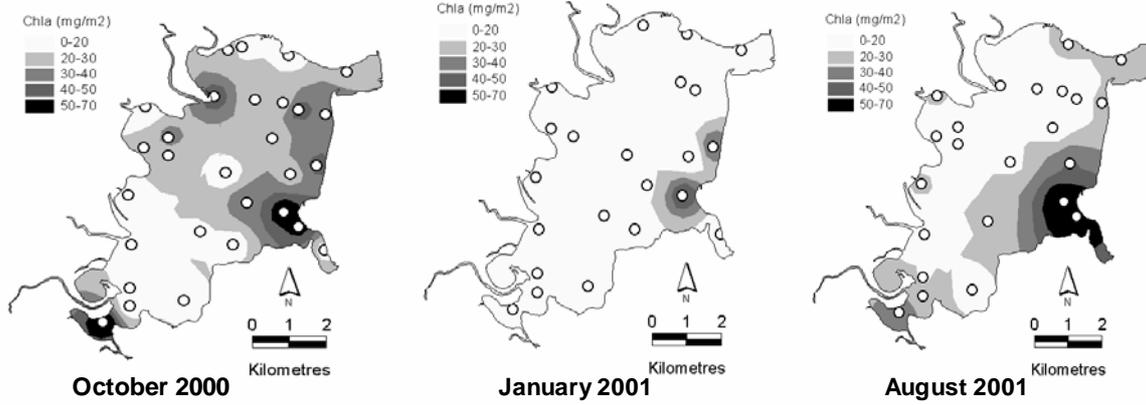
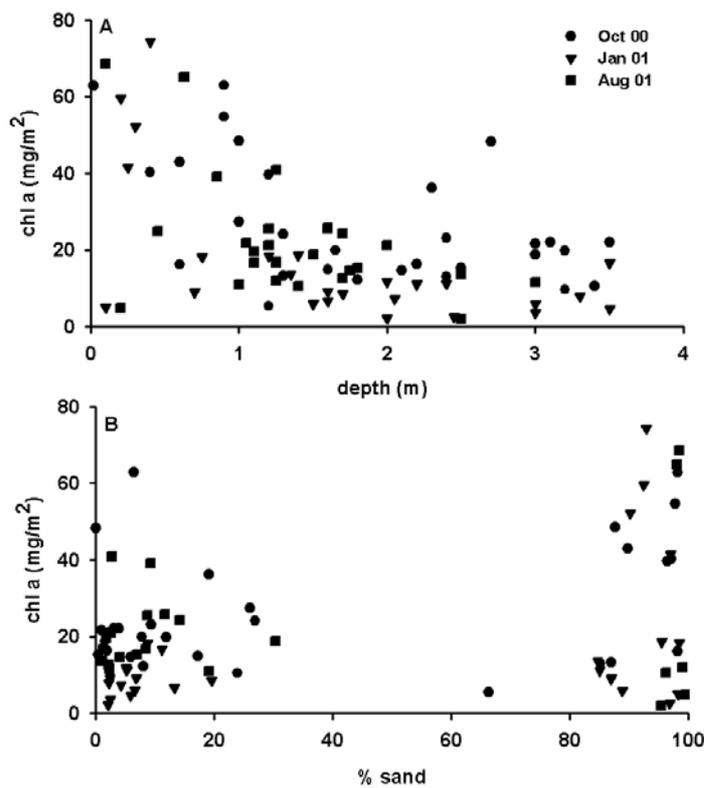


Figure 6: Biomass of benthic microalgae compared to (A) depth ($R^2 = 0.24$) and (B) % sand ($R^2 = 0.1$) at 29 sites in Lake Illawarra from samples collected throughout Lake Illawarra between October 2000 and August 2001.

DISCUSSION



This study has shown that benthic microalgae occur throughout Lake Illawarra, from shallow marine sands to fine organic muds in the deeper areas of the lake, and provided ranges of BMA biomass in major habitats and throughout the lake. The biomass of benthic microalgae in Lake Illawarra recorded in this study are within ranges reported for similar environments in Australia including Port Phillip Bay (0-68 mg/m²; Light and Beardall 1998), northern NSW estuaries (0-161 mg/m²; Gay 2002) and the Swan – Canning estuary (20-120 mg/m²; Masini and McComb 2001). Values from this study are higher than reported by Qu et al (2003) (2.5-3.9 ug/g) for sandy sediment in Lake Illawarra, but this may be due to differences in methodology. In Lake Illawarra, BMA biomass was 2-7 times higher at the shallow sandy site compared to the deep mud basin, highlighting the important contribution of shallow areas to the biological productivity of the lake. The limited frequency of sampling during this study meant that seasonal patterns were difficult to detect, and sampling at increased temporal resolution is needed to determine whether BMA exhibit seasonal patterns of abundance.

The generally higher biomass of BMA in shallow areas suggests that light is an important factor influencing the growth and distribution of BMA in Lake Illawarra. However, the range of biomass values within areas of similar depth, and the relatively low BMA biomass throughout the lake during January 2001, indicates factors other than light (temperature, sediment type, and nutrient availability) may also affect BMA. Sediment type has been shown to influence the distribution of BMA in other locations (Cahoon and Safi 2002). However, Light (1997) highlighted the difficulty of separating the effects of different factors on BMA distribution and suggests variation in BMA biomass in Port Phillip Bay is the result of a combination of factors. It is likely that this is also the case in Lake Illawarra. The variable distribution

of chlorophyll *a* values throughout the Lake Illawarra may also reflect the distribution of taxa with different chlorophyll *a* content. For example, cyanobacteria have low chlorophyll *a* content relative to diatoms. Therefore, shifts in the composition of BMA assemblages may result in variable chlorophyll *a* values.

While values of productivity of BMA in Lake Illawarra are not reported in this paper, other studies (Wilson and Johnstone, unpubl. data) and estimates by Webster *et al.* (2002) indicate that BMA contribute significantly to the primary productivity of Lake Illawarra, especially in shallow areas. In deeper areas, where light levels are at or below reported values of *I_k* (values of light at which photosynthesis is saturated), productivity is likely to be low. BMA in these environments are likely to be light limited during winter and on cloudy days. However, improvements in the water clarity are likely to result in increased BMA biomass and productivity in these areas. Further studies are required to determine the photosynthetic characteristics of BMA in Lake Illawarra.

Benthic microalgae are likely to significantly influence sediment nutrient fluxes and denitrification in Lake Illawarra, especially in shallow areas where BMA biomass and productivity is highest. BMA have been shown to enhance denitrification and reduce fluxes of nutrients from sediments to the water column. Previous published (AWT 1994) and more recent studies (Scanes, Coade and Potts, unpublished data) from Lake Illawarra have shown fluxes of nutrients from sediments in the deep mud basin are high. In addition, studies from Myall Lakes (AGSO 2000) have shown that denitrification rates are higher in shallow sandy areas where BMA are more abundant.

CONSEQUENCES FOR MANAGEMENT

One of the most important issues for Lake Illawarra is excess nutrient loads from the catchment causing eutrophication within the lake i.e. filamentous algal growth, reduced water clarity, and toxic algal blooms. Understanding the response of all primary producers in the lake to nutrient loads is critical in the development of models that can be used to determine a 'sustainable' load of nutrients for Lake Illawarra. Information collected during this study on the distribution and biomass of BMA, and the light climate of Lake Illawarra will inform these models.

This study has also highlighted the profound differences between shallow and deep areas in Lake Illawarra in terms of their physical and biological characteristics. Shallow areas are generally warmer, well oxygenated and are highly biologically active. Although these areas cover only 35% of the lake area, it is likely that they contribute a disproportionately large proportion of the biological productivity, and nutrient cycling of the lake. It is important that future modelling of the response of the lake to nutrient loads takes account of these substantial differences, so that the results of modelling are not based on over or underestimates of important parameters.

Water clarity is a crucial factor in the distribution, productivity, and growth of BMA in Lake Illawarra. This study has shown that even small increases in water clarity are likely to increase the activity of BMA in deeper areas. This would have flow on benefits to other parts of the ecosystem through increased food for benthic invertebrates, and improved cycling of nutrients. Conversely, any further decrease in water clarity will reduce the productivity of BMA in deeper areas. This may lead to increased nutrient availability for other primary producers

such as phytoplankton and filamentous macroalgae.

While this study has provided information on the biomass and distribution of BMA in Lake Illawarra, further work is needed to further investigate the taxonomic composition of benthic microalgal assemblages, factors affecting their biomass, photosynthetic characteristics, and their role in nutrient cycling.

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